

Developments of the Off-Plane X-ray Grating Spectrometer for IXO

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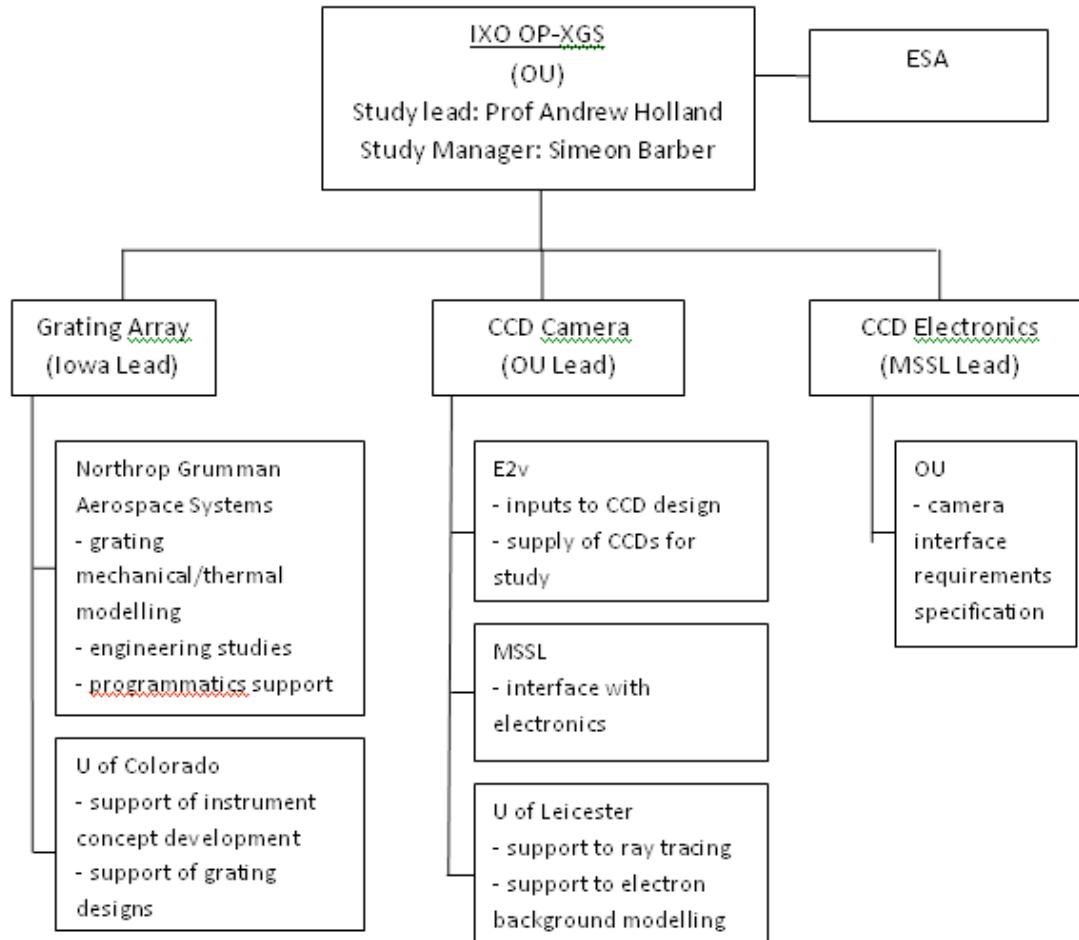
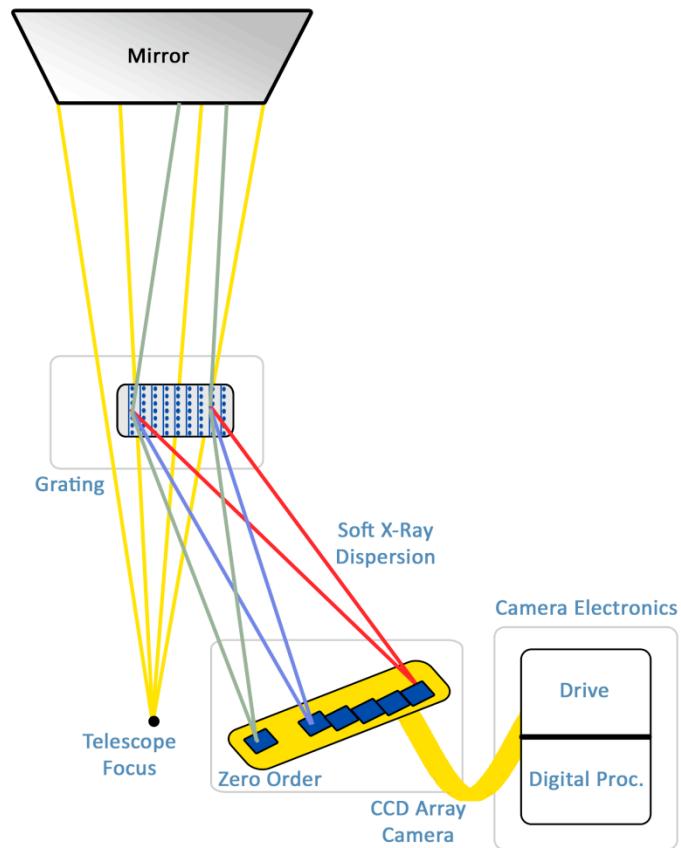
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IXO OP-XGS ESA Study Team



Key Meetings

- The project management is progressed through a series of regular telecons, with E-mail, Skype etc., face-to-face meetings, visiting fellowships...
- The OU maintains an OP-XGS project WiKi page for management of information and documentation
- Key International Meetings :
 - SRON/ESTEC - Oct 2009
 - Discuss lessons learned with SRON, many useful pointers
 - Present current thinking on OP-XGS to ESA with fruitful discussions
 - ESTEC - Dec 2009
 - IDR at ESA
 - Opportunity for the US-Europe teams to discuss options
 - Colorado – Jan 2010
 - Team meeting - discuss trade options and prepare for MTR
 - OU – March 2010
 - MTR with ESA
 - US-Europe team meeting
 - ESTEC – July 2010
 - IPRR with ESA
 - US-Europe team meeting



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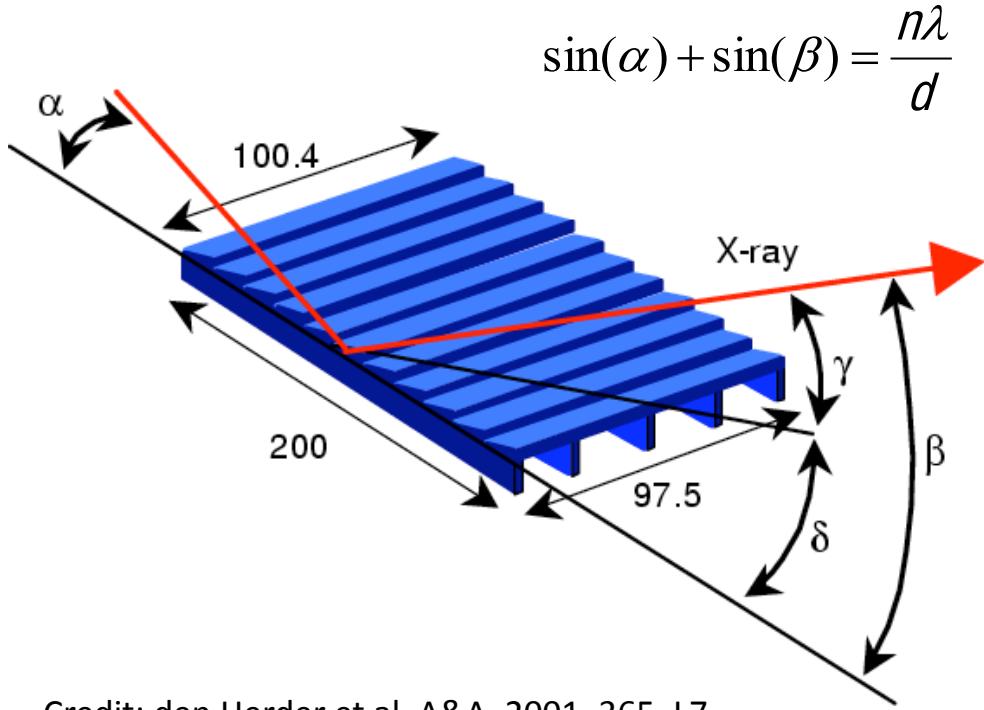
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“Traditional” grating arrays



Credit: den Herder et al. A&A, 2001, 365, L7

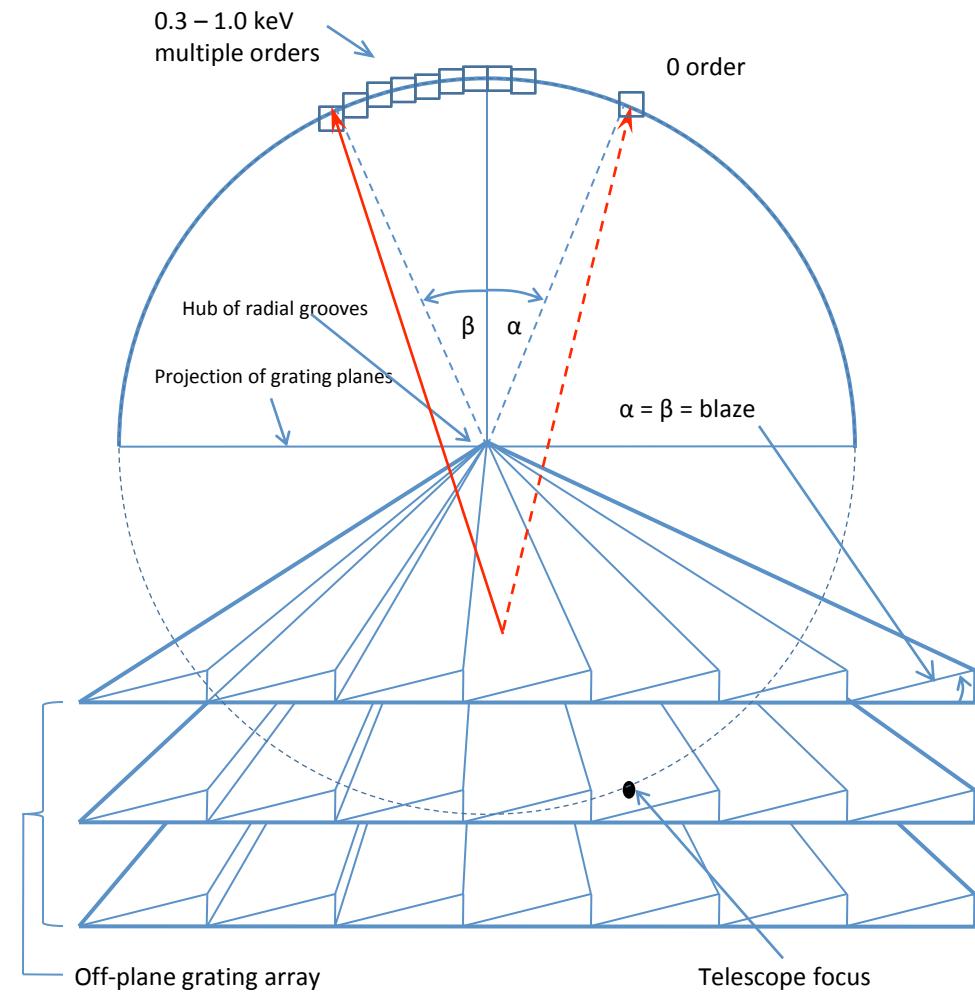
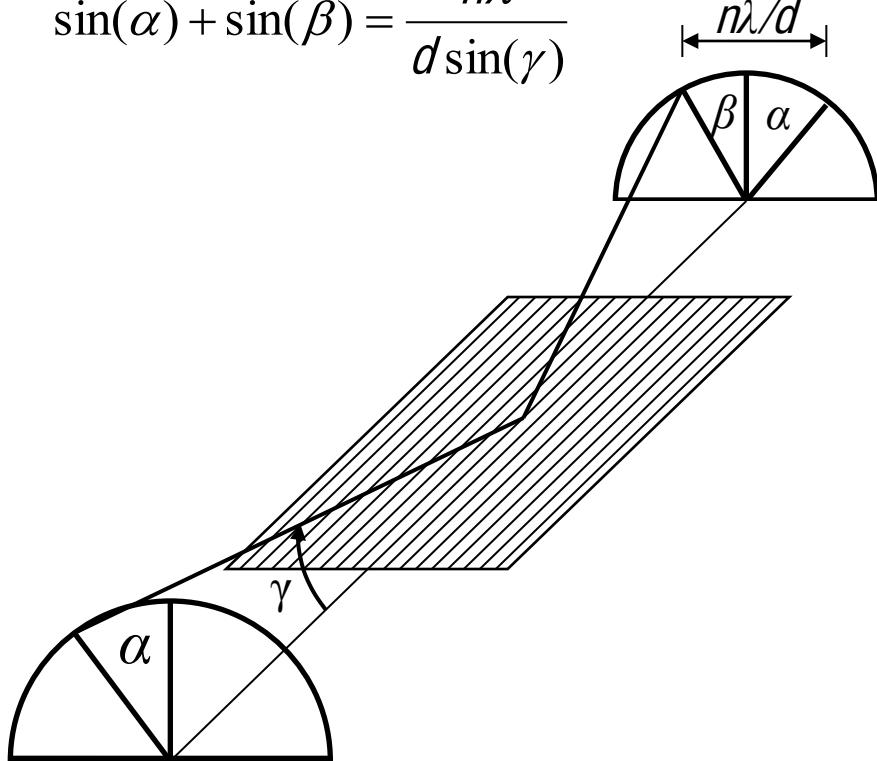


XMM RGS

In-plane (transmission gratings also disperse in plane of incident light)

Off-plane gratings

$$\sin(\alpha) + \sin(\beta) = \frac{n\lambda}{d \sin(\gamma)}$$



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Off-plane flight heritage

-Sounding rocket, Cash / Wilkinson, 1992

- Aluminum substrate, 250mm x 100mm x 12mm
- Mechanically ruled, replicated
- 1 grating

-Sounding rocket, Cash / Gallagher, SCOX1 1993

- Aluminum substrate, 110mm x 110mm x 16mm
- Mechanically ruled, replicated
- 4 gratings

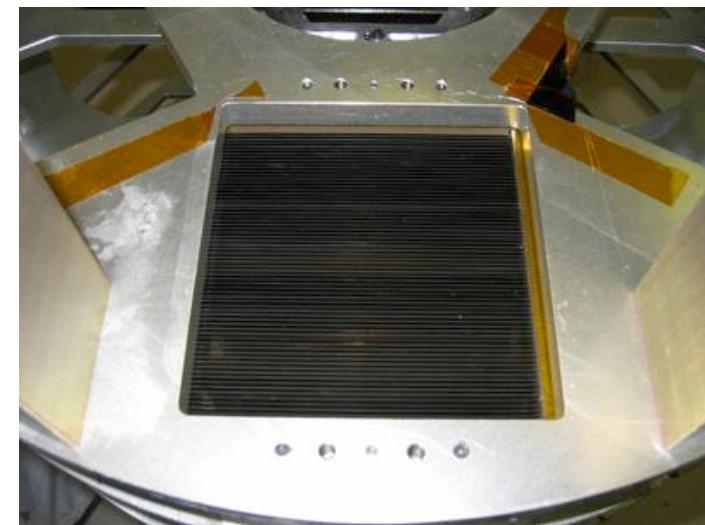
-Sounding rocket, Catura/Cash, XOGS 1994

- Aluminum substrate, 500mm x 300mm x 3mm
- Mechanically ruled, replicated
- 6 gratings per array

-Sounding rocket, Cash/McEntaffer, CYXESS 2007 &

-Sounding rocket, Cash/Oakley/McEntaffer, EXOS 2009

- EF Nickel substrate, 104mm x 20mm x 127 microns
- Holographically recorded, replicated grooves, 5670 gr/mm
- 62 gratings per array x 2 arrays



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IXO Instrument Key Performance Requirements

Mirror Effective Area	3 m ² @ 1.25 keV 0.65 m ² @ 6 keV with a goal of 1 m ² 150 cm ² @ 30 keV with a goal of 350 cm ²	Black hole evolution, large scale structure, cosmic feedback, EOS Strong gravity, EOS Cosmic acceleration, strong gravity
Spectral Resolution	$\Delta E = 2.5 \text{ eV}$ within $2 \times 2 \text{ arc min}$ (0.3 – 7 keV) . $\Delta E = 10 \text{ eV}$ within $5 \times 5 \text{ arc min}$ (0.3 - 7 keV) $\Delta E < 150 \text{ eV}$ @ 6 keV within 18 arc min diameter (0.1 – 15 keV) <u>E/ΔE = 3000 from 0.3–1 keV with an area of 1,000 cm² for point sources</u> $\Delta E = 1 \text{ keV}$ within $8 \times 8 \text{ arc min}$ (10 – 40 keV)	Black Hole evolution, Large scale structure Missing baryons using tens of background AGN
Mirror Angular Resolution	$\leq 5 \text{ arc sec HPD}$ (0.1 – 10 keV) 30 arc sec HPD (10 - 40 keV) with a goal of 5 arc sec	Large scale structure, cosmic feedback, black hole evolution, missing baryons Black hole evolution
Count Rate	1 Crab with >90% throughput. $\Delta E < 200 \text{ eV}$ (0.1 – 15 keV)	Strong gravity, EOS
Polarimetry	1% MDP on 1 mCrab in 100 ksec (2 - 6 keV)	AGN geometry, strong gravity
Astrometry	1 arcsec at 3σ confidence	Black hole evolution
Absolute Timing	50 μsec	Neutron star studies
    		e2V

Previous empirical off-plane data

- Off-plane grating development for IXO
 - Radial, blazed gratings have been fabricated and efficiency tested **40% (sum of orders) dispersion efficiency has been obtained** (McEntaffer, et al. 2004, SPIE).
 - Resolution testing has been performed on a *telescope limited* system (3' HPD) and a **resolution of >200** was obtained (Osterman, McEntaffer, et al. 2004, SPIE). Assuming the grating adds no aberration, a 5" HPD quality telescope puts the resolution at **>7200**.
 - A **prototype IXO grating has been fabricated** and is awaiting X-ray testing. Efficiency tests will be performed at the University of Iowa upon completion of an X-ray test facility. Also, the grating will be resolution tested in a test facility at Colorado and in the beam of the IXO SXT optics at the GSFC X-ray beamline. **Zeiger et al. Poster 7732-149**

Major Trade Study Options

- Focused on the overall configuration
- Culminates in Instrument Preliminary Requirements Review

Gratings

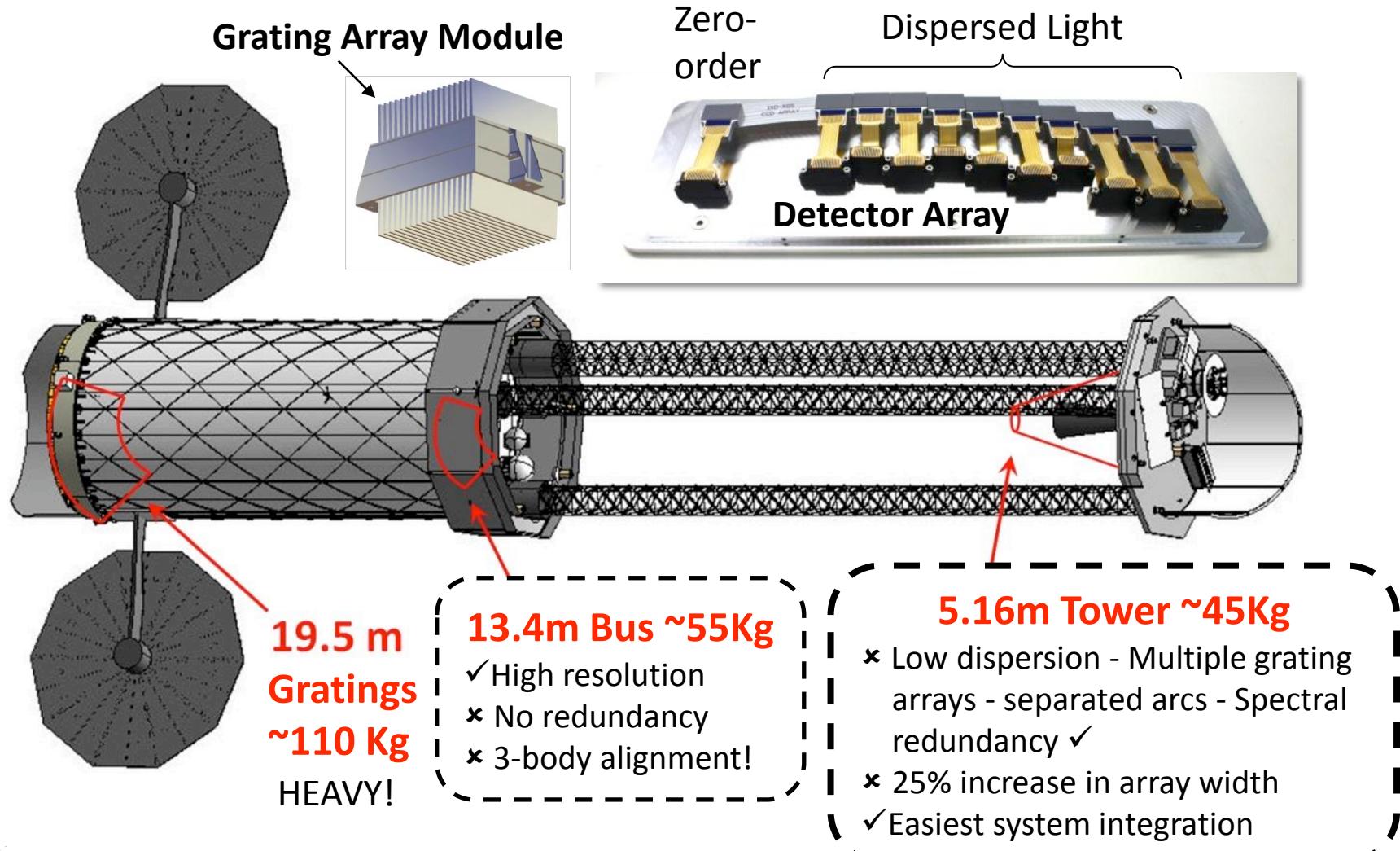
- Three options were studied
 - 19.5 m position – behind the optics
 - **13.4 m position – service module (in PDD)**
 - 5.16 m position – tower solution
- Assuming a static grating fixed in the beam
- Design to meet effective area and resolution requirements

Camera

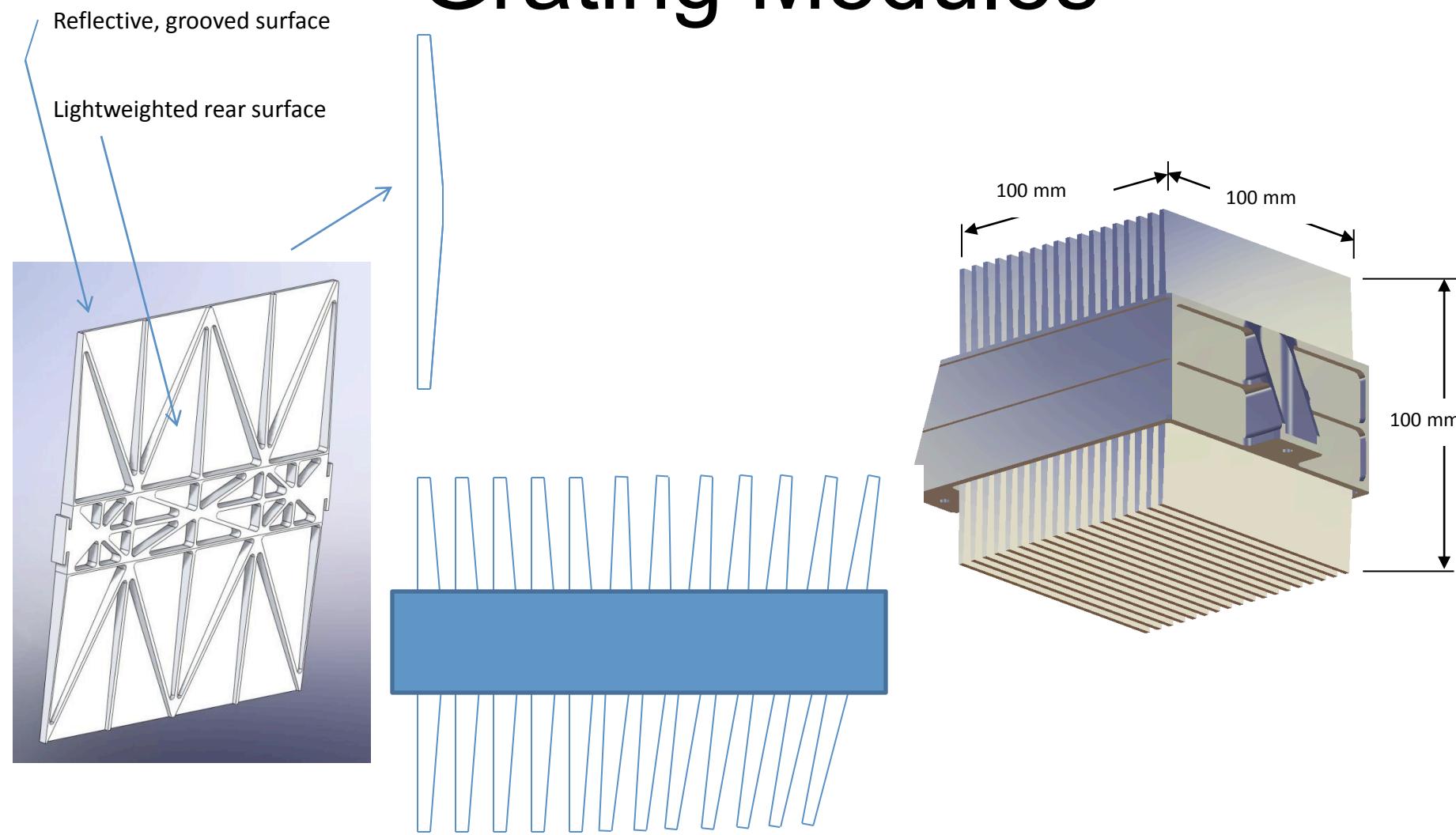
- Focal plane layout optimisation for each grating option
- **Baseline array uses array of standard back-illumination CCDs**
- EM CCD option for enhanced performance (increased S/N + extension to 200 eV)
 - **James Tutt, 7742-33**



ESA Instrument Trade Study for IXO

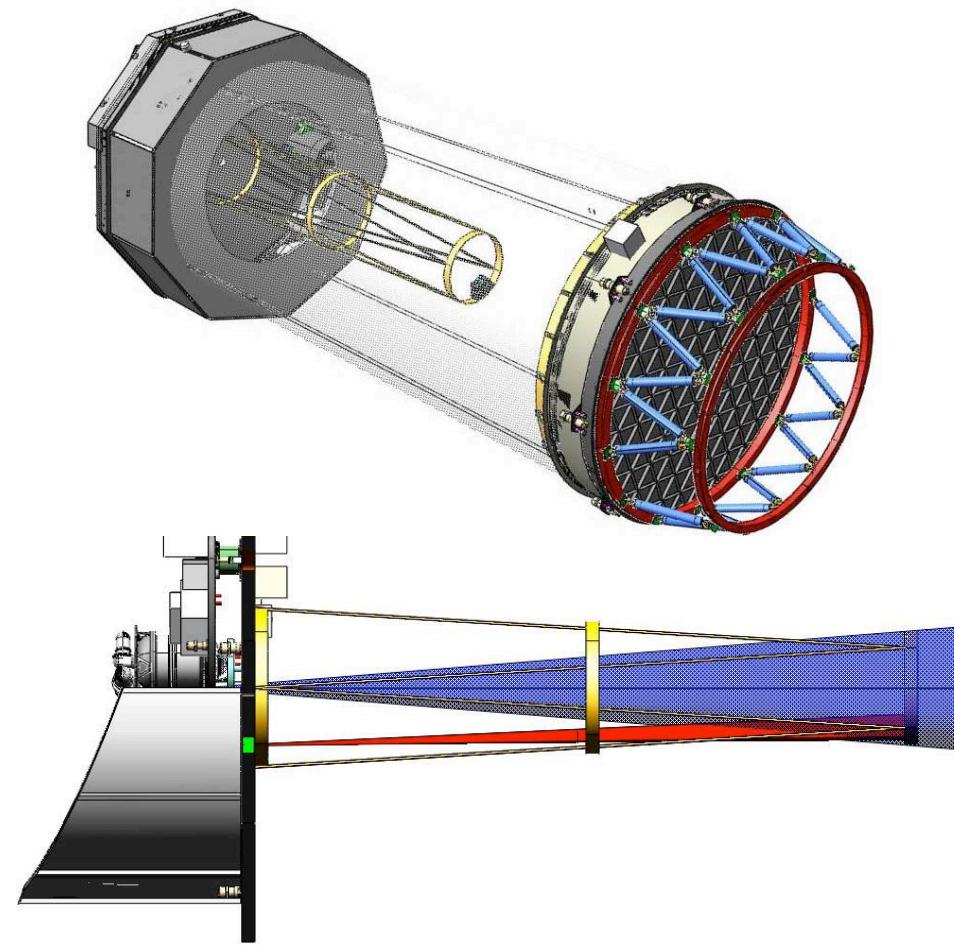


Grating Modules

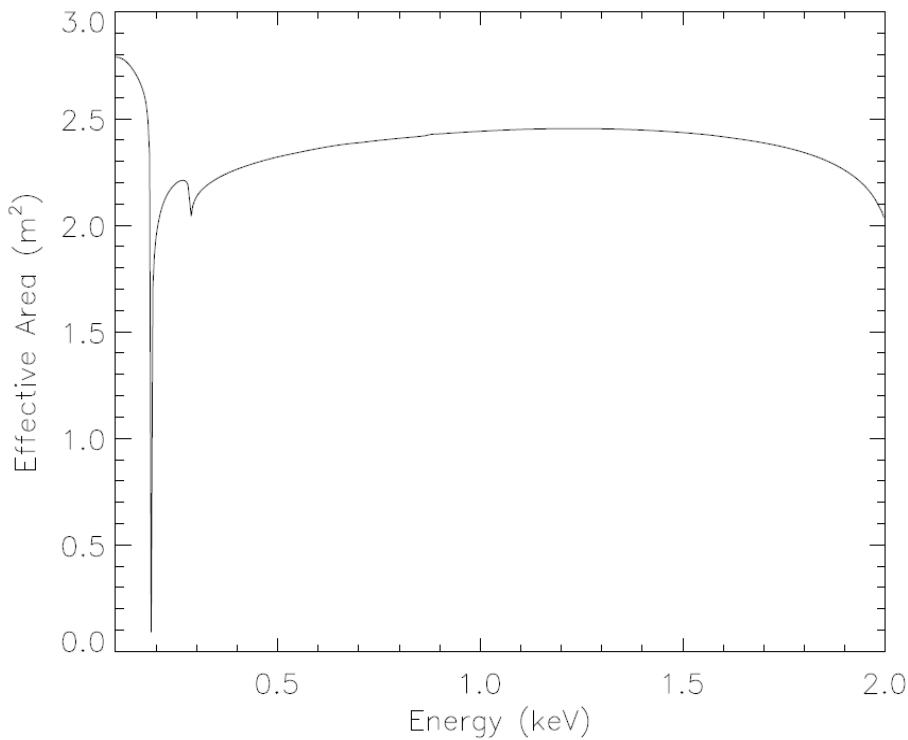


Gratings on a Tower

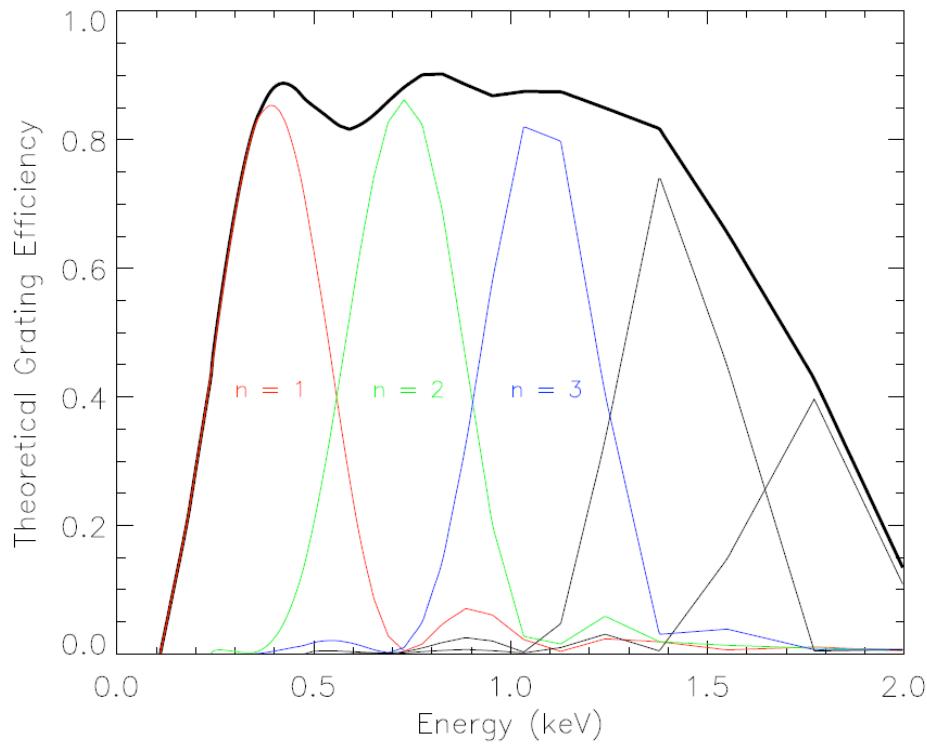
- Tower can accommodate system instrumentation
 - Common baffle for prime focus instruments
 - MLI wrap for stray light
 - Magnets for particle scrubbing
 - Cold surfaces for contamination mitigation



Effective Area Calculations

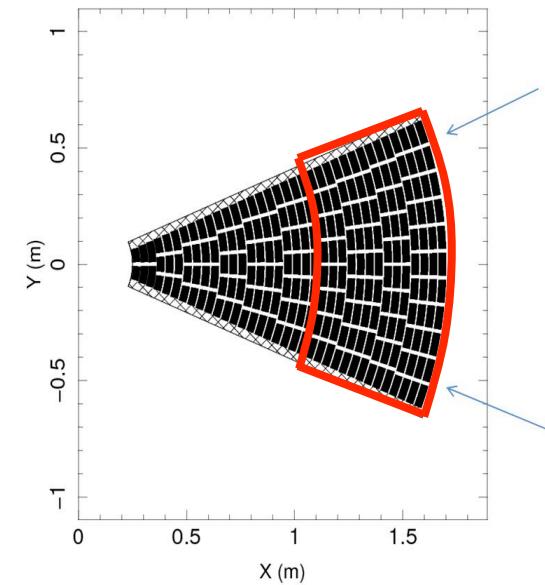
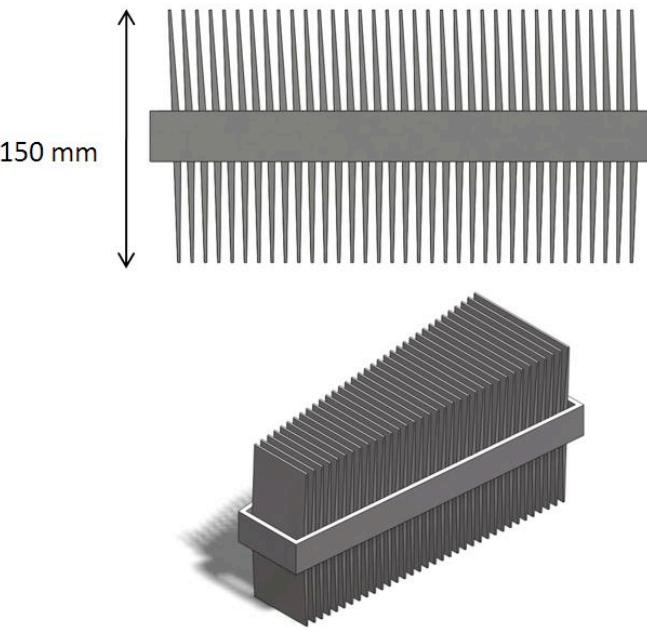
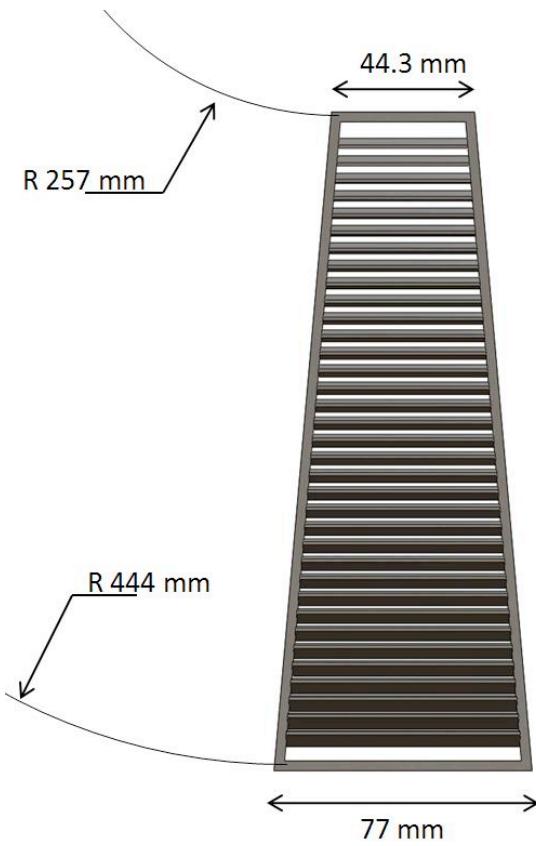


8 nm B_4C coating over Ir
Includes 10% margin loss



Theoretical grating efficiencies from AFM
measurements of prototype grating

Tower Modules

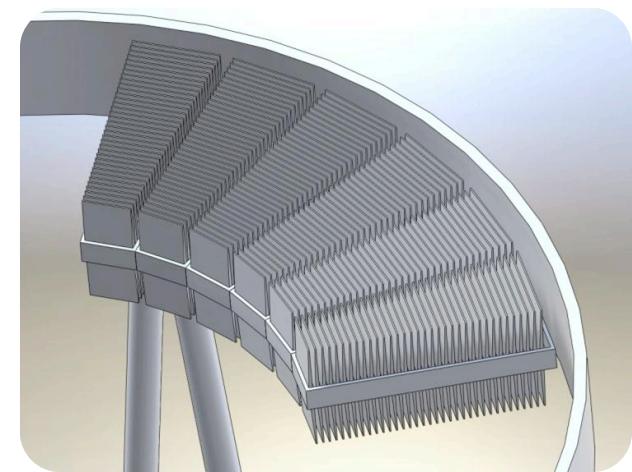


Projected to telescope
Covers radii from
1.0-1.7 m

39 gratings, $\sim 2.5^\circ$
Azimuthal span limits resolution, 11°

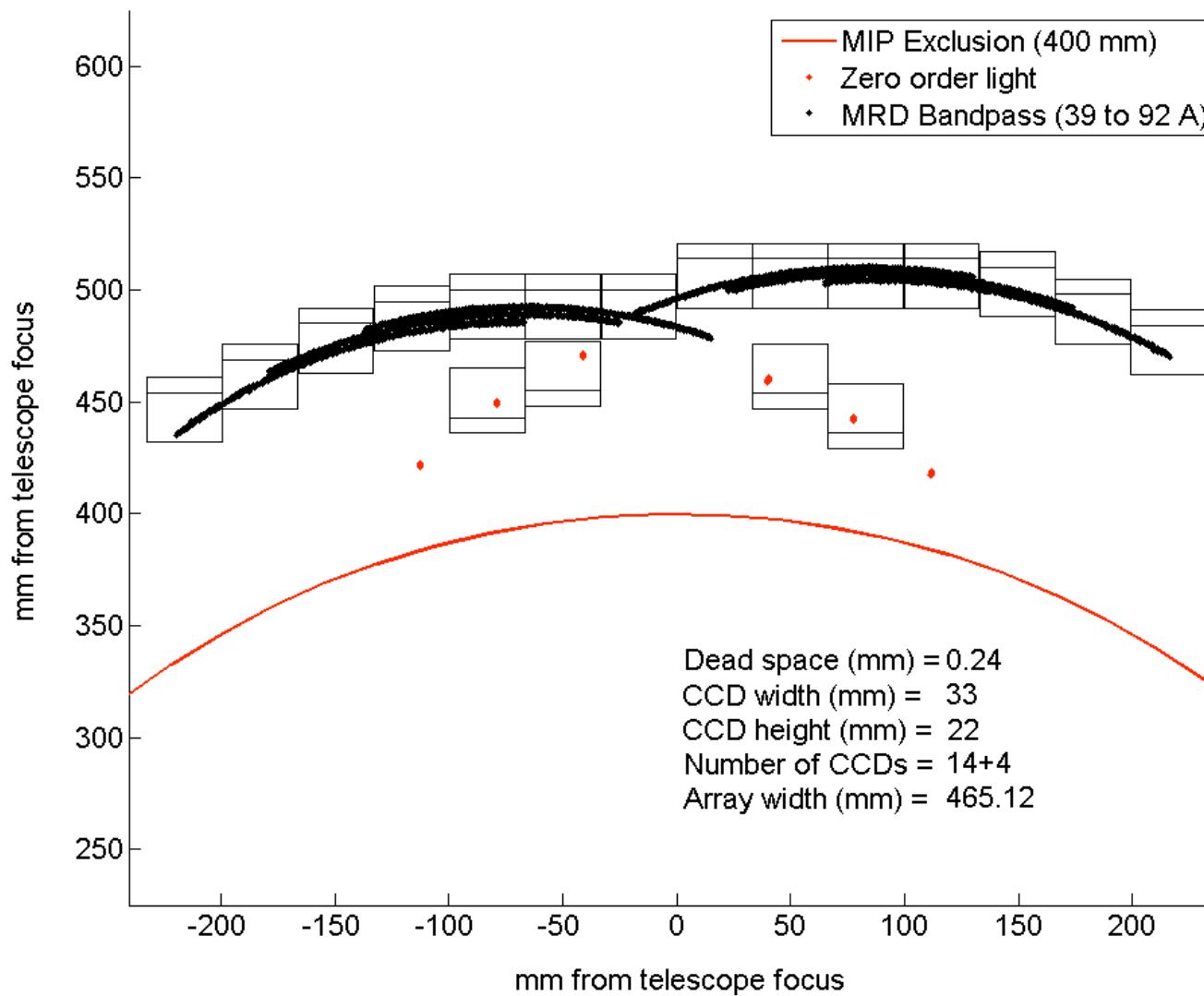
OPXGS parameters	6 modules
Telescope mirror model	SPO, B ₄ C coat, outer 35 rows, 10% loss, March 24, 2010
Telescope beam obscuration (gratings)	13%
Telescope beam obscuration (structure)	0.3-2.0%
Grating module azimuthal coverage	11°
Grating module radial coverage (at the telescope)	1.00-1.72 m
Number of modules	6
Gratings per module	39
Grating mechanical throughput	93%
Grating graze angle	2.5°
Grating diffraction efficiency (no coating)	~90%
Reflective coating	Ir
Groove length	150 mm
Grating edge thickness	0.5 mm
CCD optical blocking filter thickness	28 nm Al, 13 nm MgF ₂
Average effective area	1500 cm ²
Effective area @ 300 eV	1000 cm ²
Effective area contingency	30%
TRL	3: technology development must be performed

Grating Array Parameters

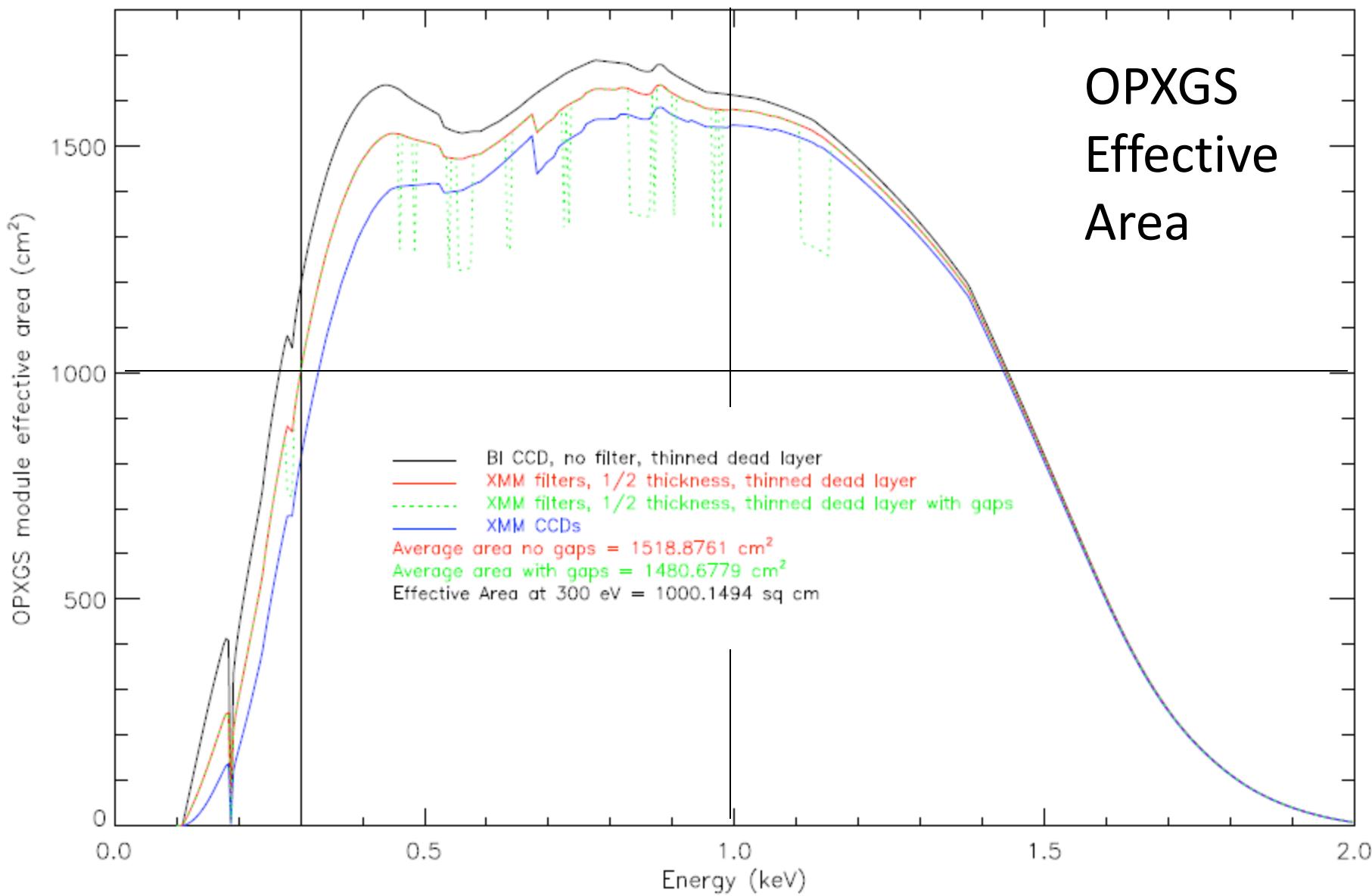


CCD array layout

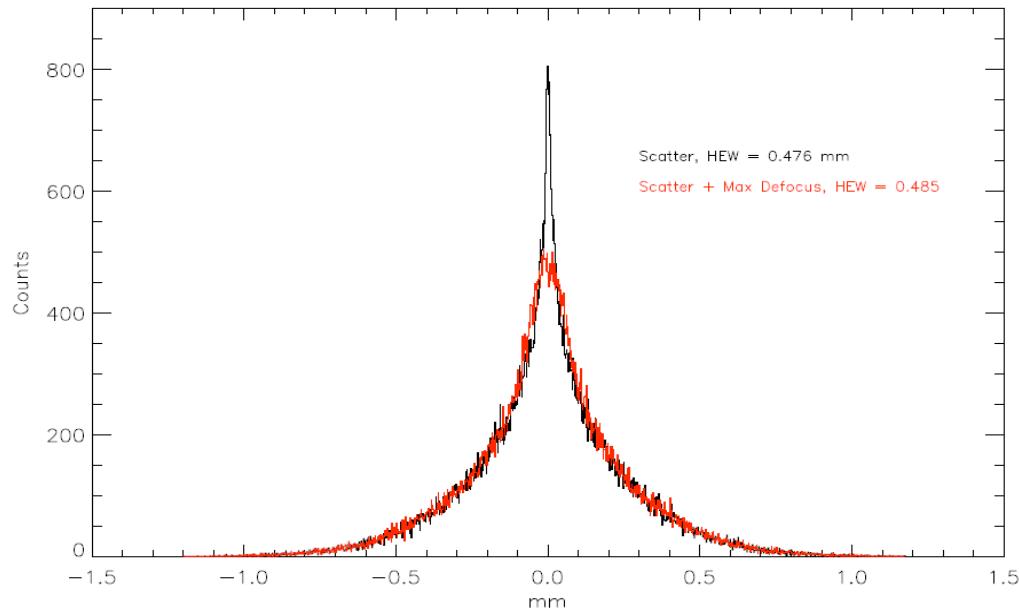
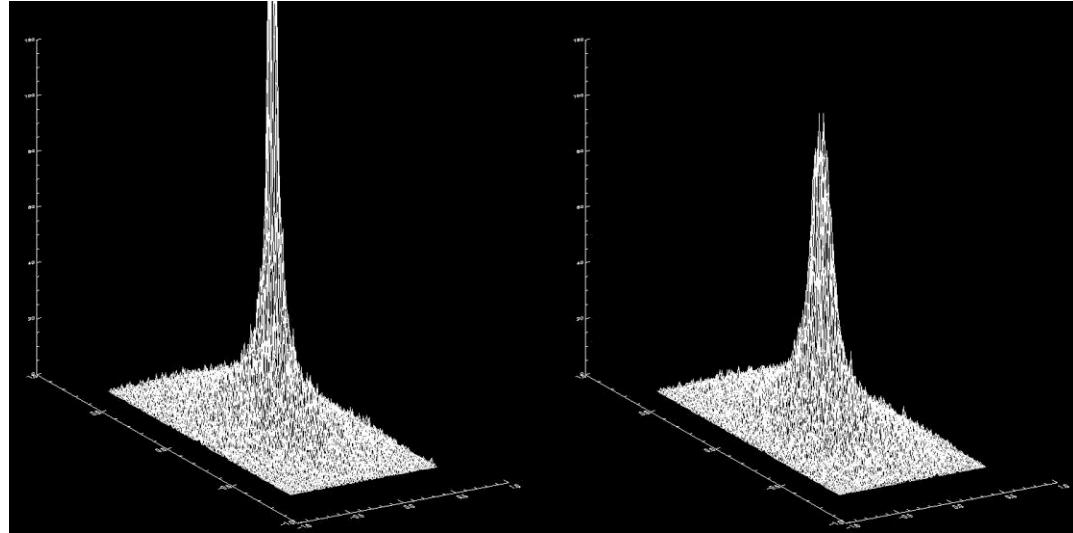
Murray, et al. 7742-95



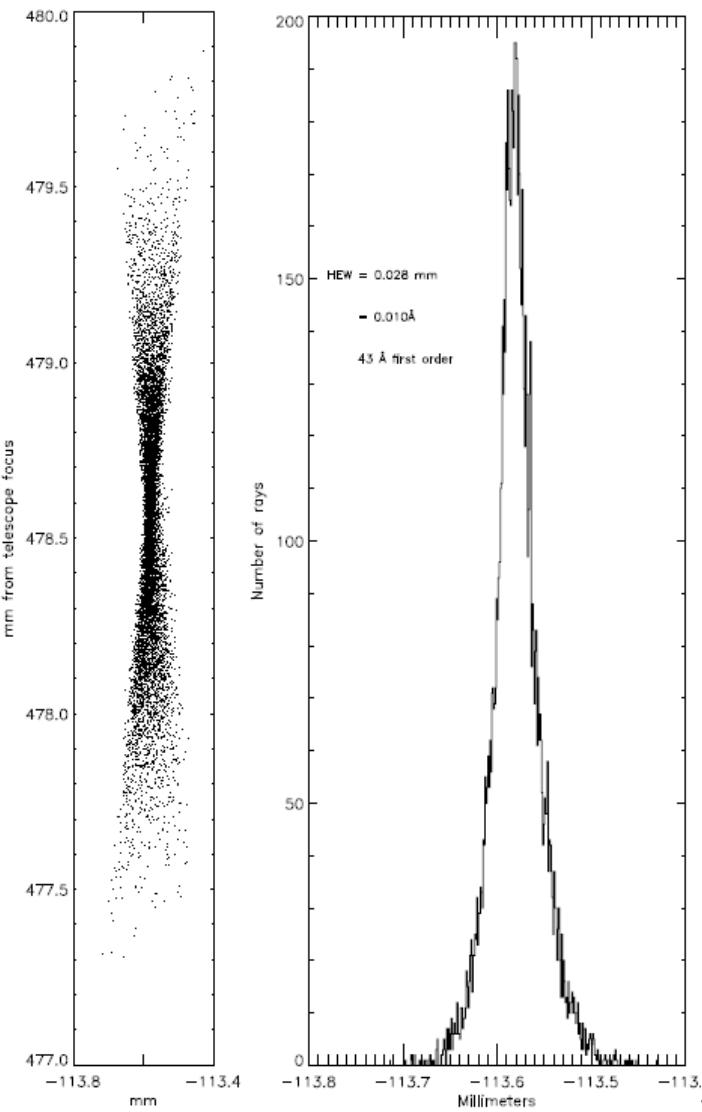
OPXGS Effective Area



Raytrace Verification of Resolution

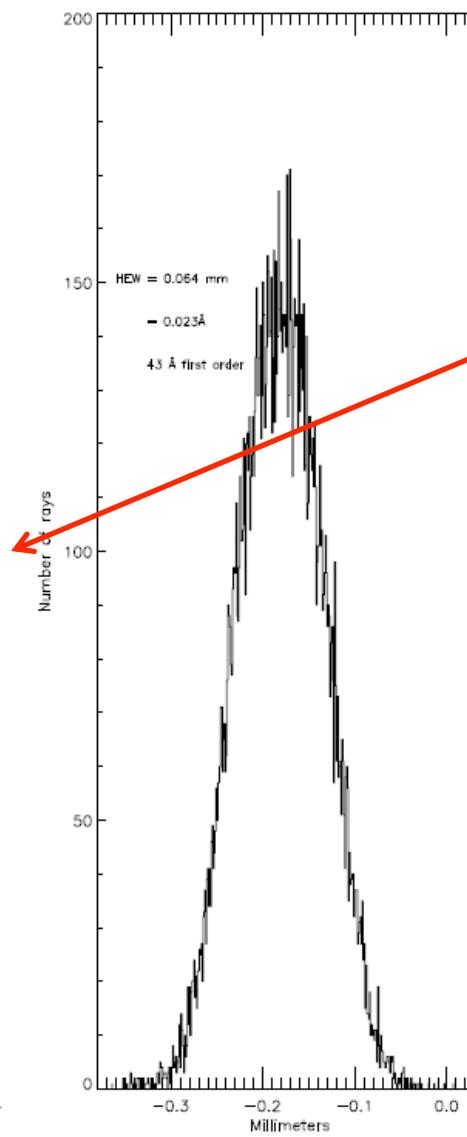
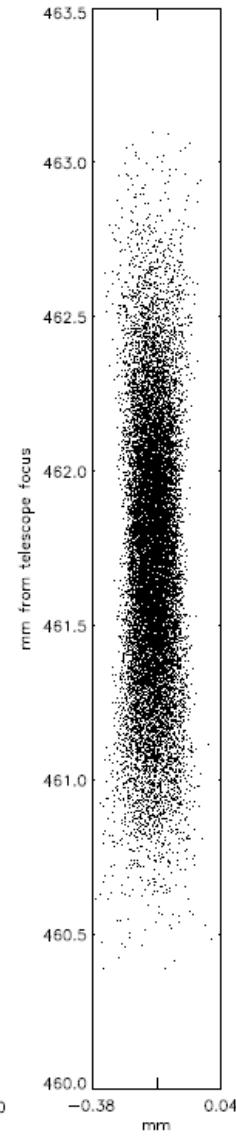
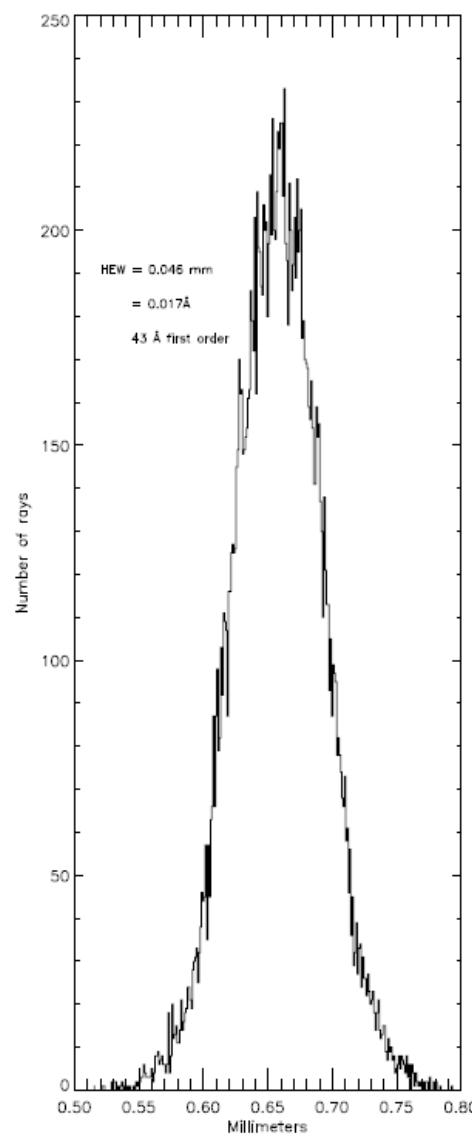
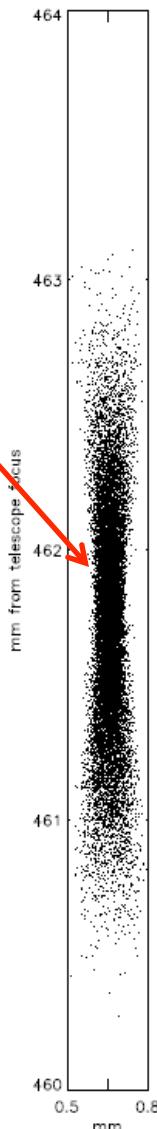


HEW = 0.028 mm, 0.010 Å



Degree of defocus

Add 1"
pointing
errors



Add 1"
pointing
errors +
1.2" image
quality
errors

HEW =
0.064 mm
0.023 Å



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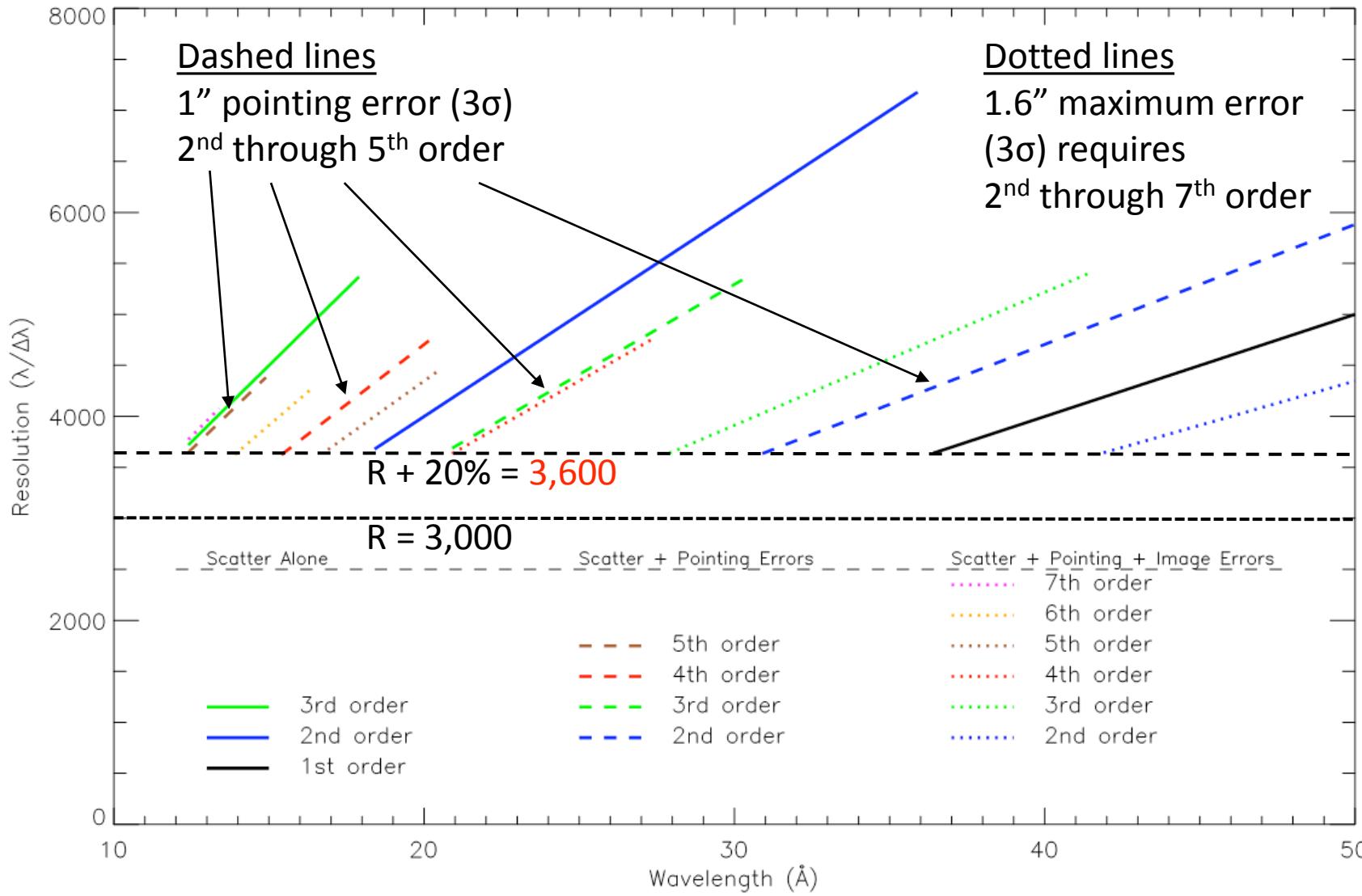
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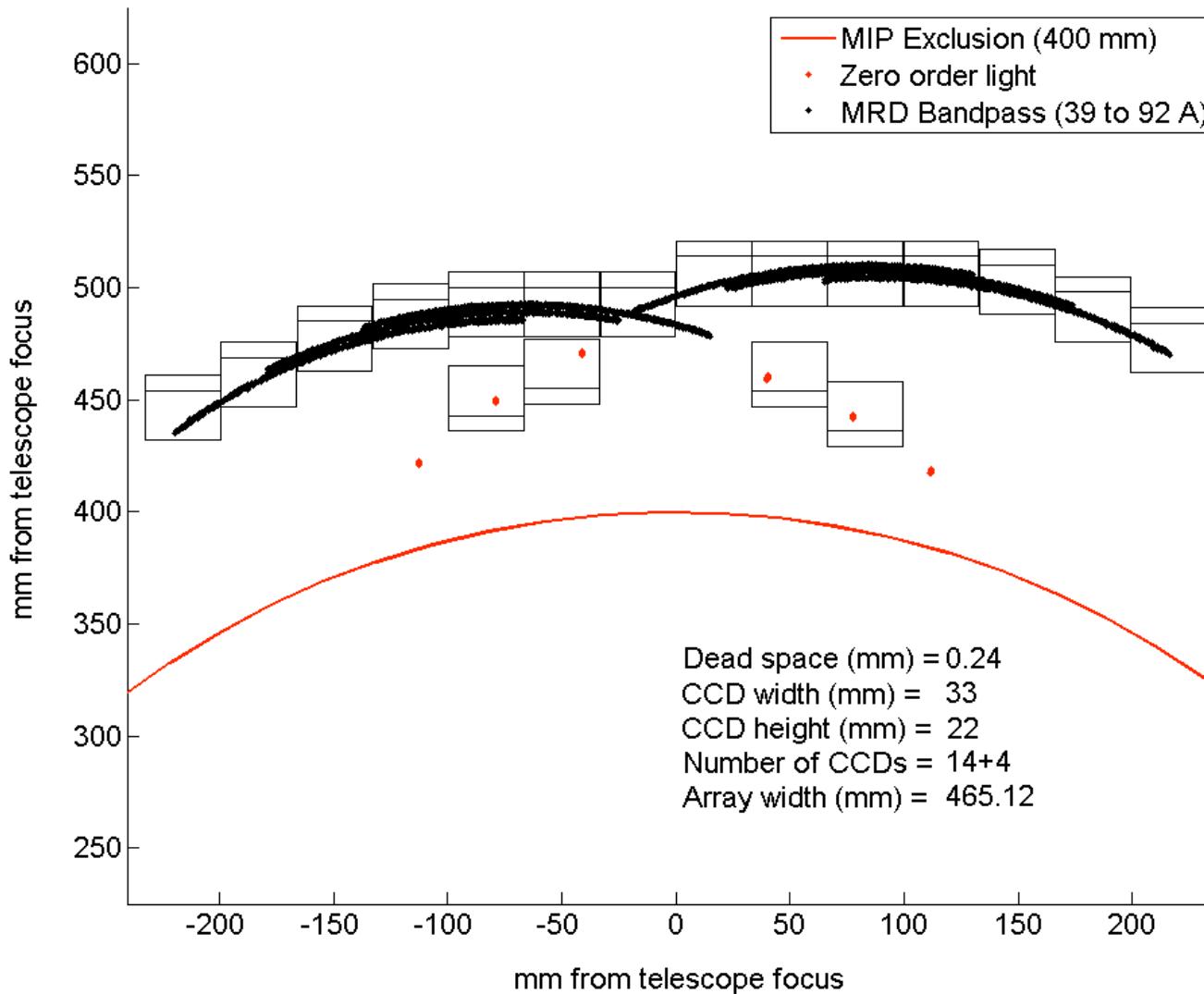
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Resolution Comparison

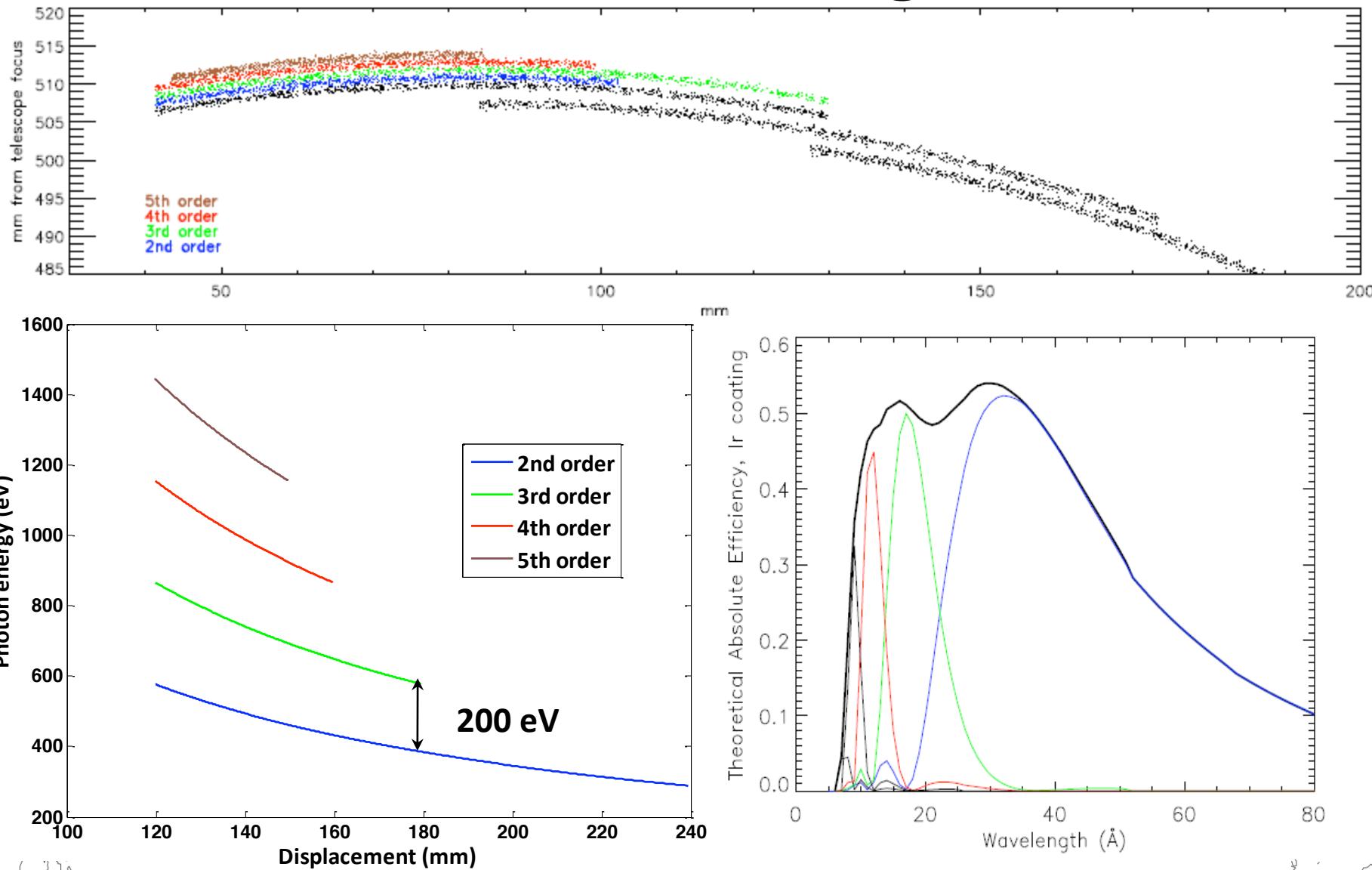


CCD array layout



Murray, et al. 7742-95

Order sorting



Grating Thermal Analysis

	Option 1	Option 2	Mass Per Unit
Part	Quantity	Quantity	(kg, ~25% Cont.)
NG Heaters	8	5	0.003 (TBC)
NG Thermistors	16	18	0.003 (TBC)
Grating Module Thermal Control Hardware (MLI / SLI)	1 set	1 set	0.4 (TBR)
Radiative Heater Panels	0	5	0.1 (TBR)
Cable Harness	1	1	2.9 (TBR)
Controller Board	1	1	1.2 (TBR)

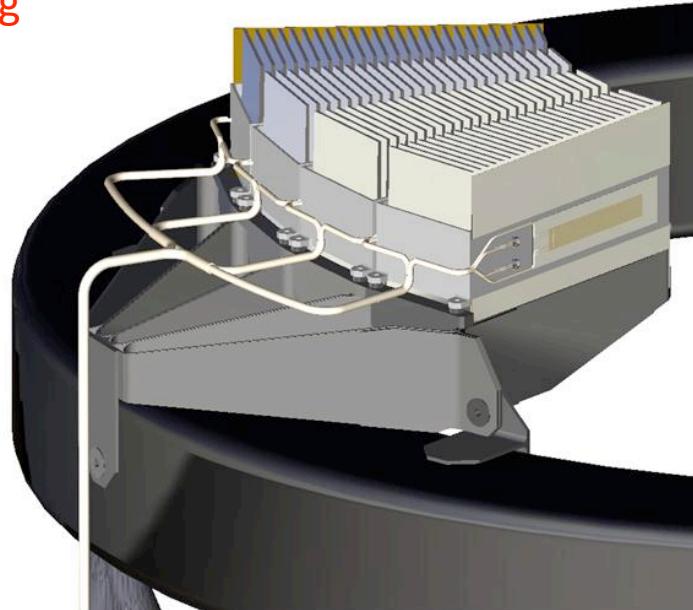
Top Level OP-XGS Thermal Equipment List

Maintains grating-to-grating

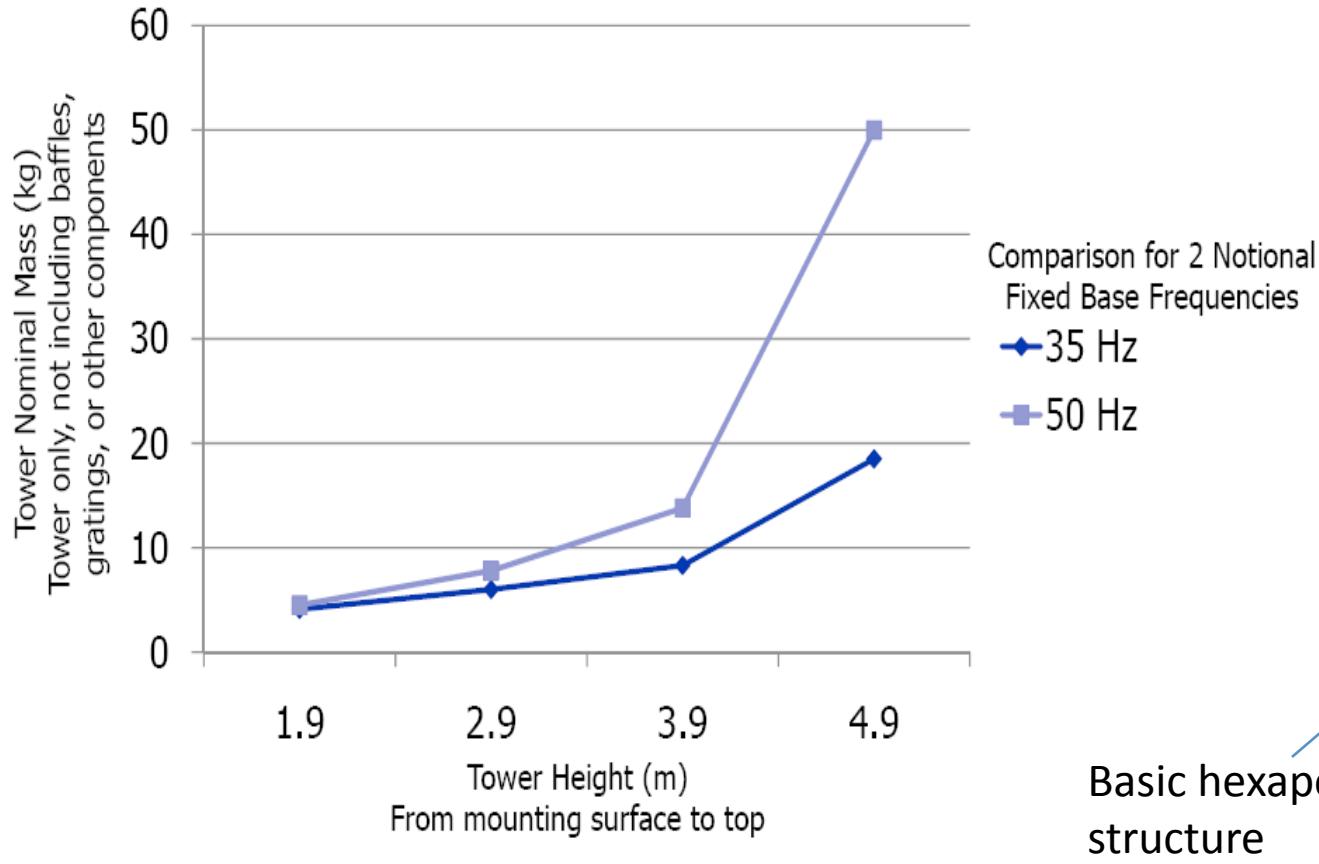
$T_{\text{grad}} < 15 \text{ mK}$

(<350 mK all sun angles)

<19 W power



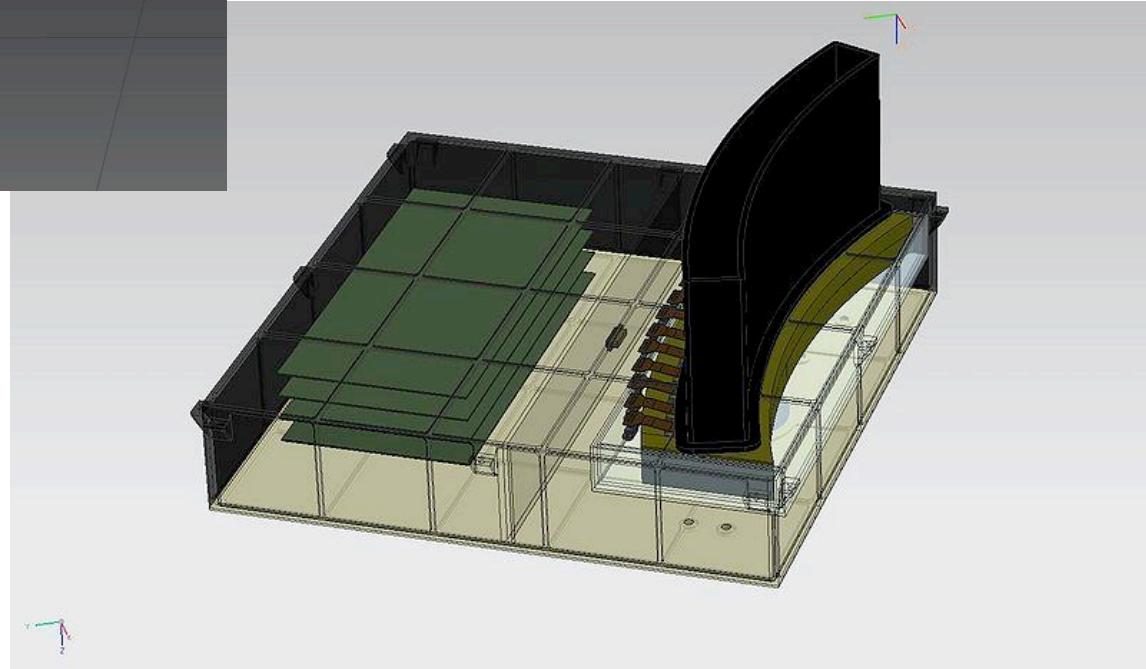
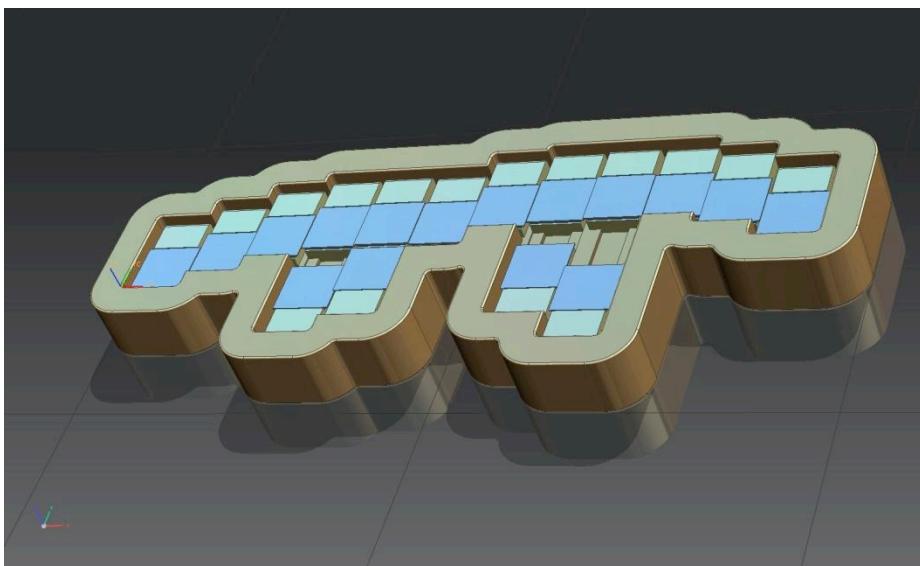
Tower structure mass



Basic hexapod
structure



CCD Camera



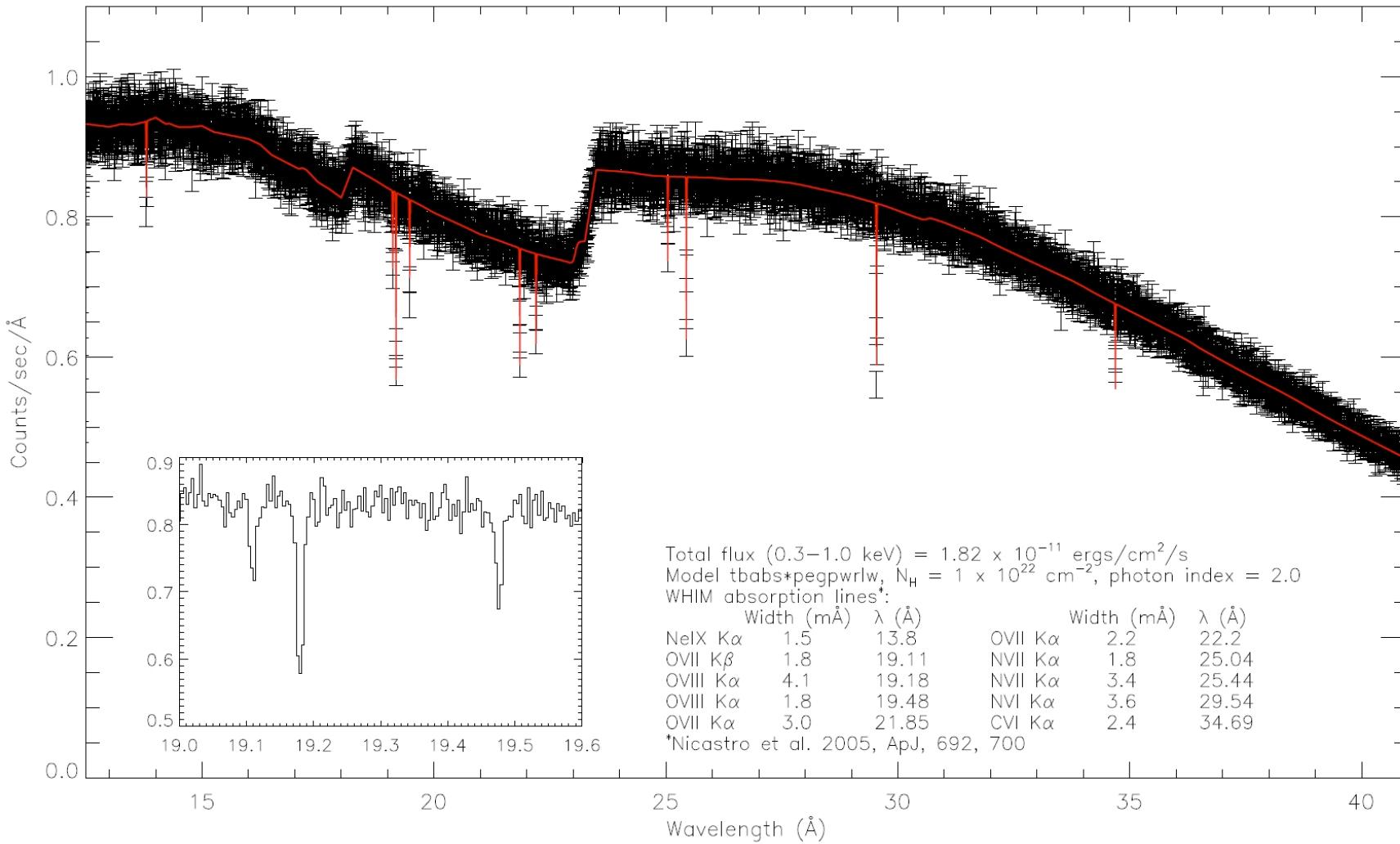
System Mass (kg)

ITEM	QTY	MASS	TOTAL (no margin)	TOTAL (20% margin)
			31.0	37.2
GRATING ARRAY GA				
Array structure			5.000	6.000
Tower	1	20.000	20.000	24.000
Module structure			3.000	3.600
Grating			3.000	3.600
			0.8	1.0
GRATING CONTROL GC				
NG Heaters	12	0.003	0.036	0.043
NG Thermistor	27	0.003	0.081	0.097
Radiative heater panels	7	0.100	0.7	0.840
TOTAL for GS = GA + GC			31.8	38.2
CAMERA HEAD CH				
FRONT RADIATION SHIELD (BAFFLE)	1	8.000	8.000	9.600
BOX	1	6.700	6.700	8.040
BOX LID	1	3.700	3.700	4.440
CCD PACKAGE (EXCLUDING CONNECTOR)	18	0.050	0.900	1.080
CONNECTOR (CAMERA SIDE)	18	0.015	0.270	0.324
CONNECTOR (PCB SIDE)	18	0.015	0.270	0.324
CONNECTOR (BULKHEAD)	18	0.015	0.270	0.324
COLD BENCH	1	5.000	5.000	6.000
INTERNAL SUPPORT STRUCTURE	1	0.500	0.500	0.600
HEAT SHIELDING AROUND BENCH	1	1.000	1.000	1.200
COLD FINGER	2	0.300	0.600	0.720
COLD FINGER THERMAL BREAK	2	0.200	0.400	0.480
DOOR INC. MECHANISM/ACTUATOR	1	2.000	2.000	2.400
M5x24 MOUNTING SCREWS	30	0.005	0.150	0.180
CAMERA ELECTRONICS CE				
Card 0 - Power Converter	1	1.250	1.250	1.500
Card 1 - Driver/Analogue/ADC	1	2.000	2.000	2.400
Card 2 - Driver/Analogue/ADC	1	2.000	2.000	2.400
Card 3 - Digital Processing	1	1.000	1.000	1.200
Card 4 - Instrument Control/ spacecraft i/f / thermal control / HK	1	1.500	1.500	1.800
Internal harness, support, screen, structure	1	1.000	1.000	1.200
Harness (s/c to CE box)	2	1.500	3.000	3.600
Card 5 - Gratings Control	1	1.000	1.000	1.200
Harness (CE to Gratings Array)	1	3.000	3.000	3.600
TOTAL for CS = CH + CE			45.4	54.4

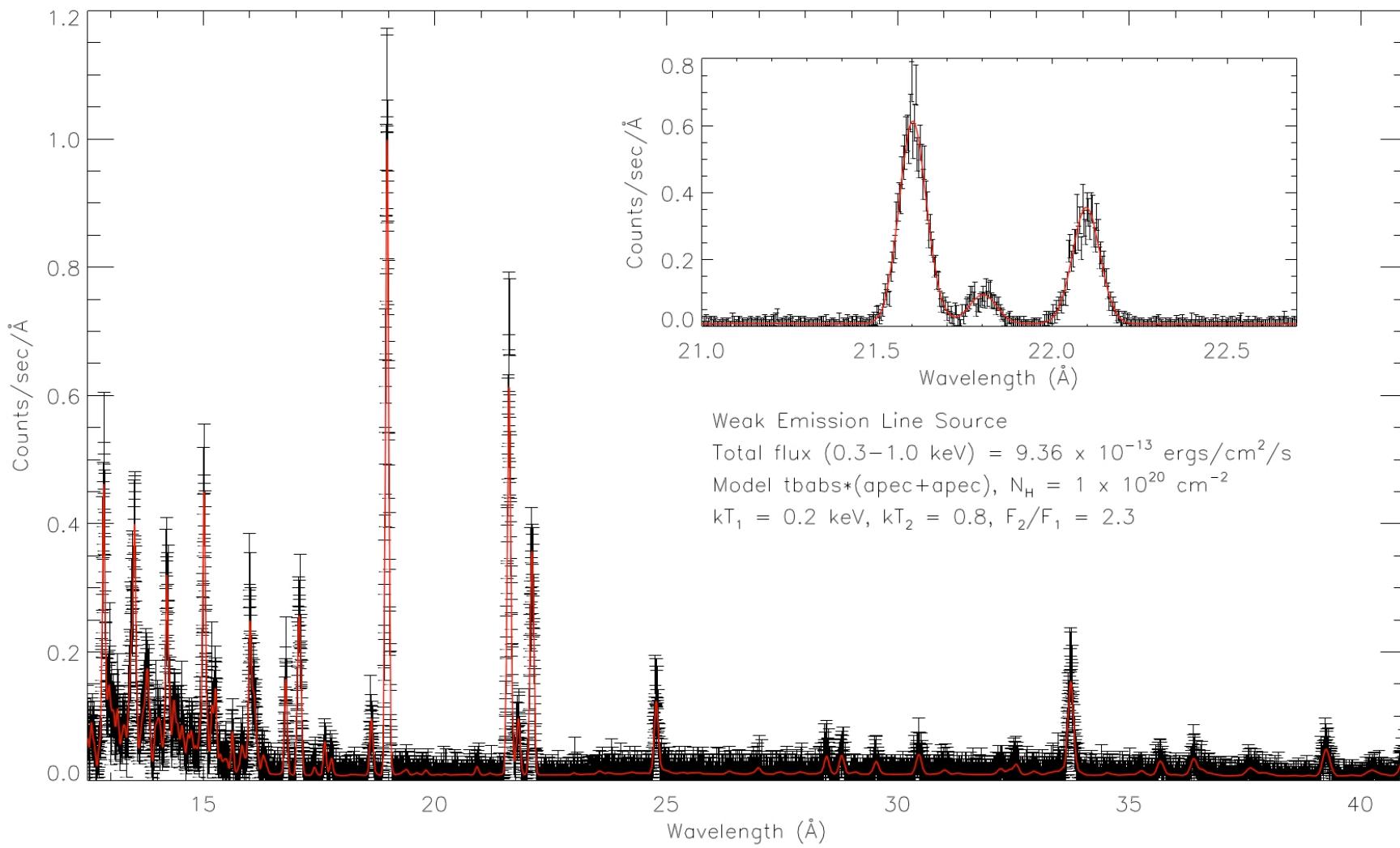
OPXGS TOTAL = CS + GS

75.4 **90.5**

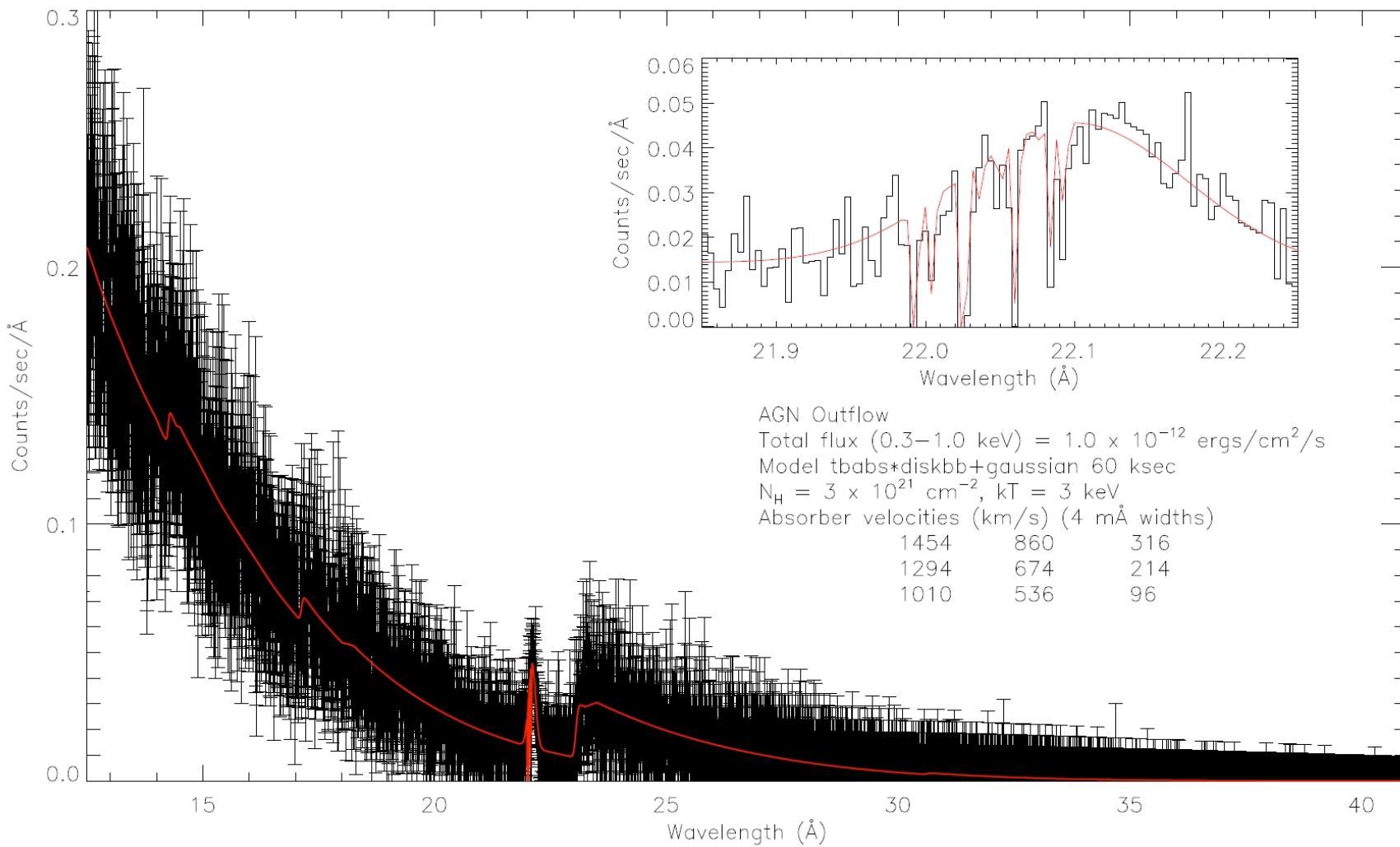
OP-XGS Science Simulations - WHIM



OP-XGS Science Simulations – Line Emission



OP-XGS Science Simulations – AGN Outflows



Conclusions

- ESA Instrument Study has been completed
- Results
 - Well characterized design
 - Effective area $>1000 \text{ cm}^2$ ($\sim 1500 \text{ cm}^2$ band average)
 - Resolution $> 3600 (\lambda/\Delta\lambda)$ over range of defocus
 - Maturing camera design with high TRL
 - Tower integrates system components
- IPRR, ESA, July 14th